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Treatment of domestic effluents in a biological system of nanoceramic membranes for forest reuse purposes

Tratamento de Efluentes Domésticos em Sistema Biológico de Membranas Nanocerâmicas para Fins de Reúso Florestal

Igor Duarte Rosa Lima[1]; Vicente de Paulo Silva[2]; Rosângela Gomes Tavares[3]; Alex Souza Moraes[4], Ronaldo Faustino da Silva[5]

[1] Federal Rural University of Pernambuco, Graduate Program in Environmental Engineering, Recife/PE, Brasil. Email: igorduarterl@hotmail.com
ORCID: https://orcid.org/0000-0002-7781-9685

[2] Federal Rural University of Pernambuco, Graduate Program in Environmental Engineering, Recife/PE, Brazil. Email: vicenteufrpe@yaho.com.br
ORCID: https://orcid.org/0000-0002-1435-9335

[3] Federal Rural University of Pernambuco, Graduate Program in Environmental Engineering, Recife/PE, Brazil. Email: rosangelagomestavares@ufrpe.br
ORCID: https://orcid.org/0000-0001-8400-3759

[4] Federal Rural University of Pernambuco, Graduate Program in Environmental Engineering, Recife/PE, Brazil. Email: alex.moraes@ufrpe.br
ORCID: https://orcid.org/0000-0002-4324-8271

[5] Federal Institute of Pernambuco, Department of Environment, Recife/PE, Brazil. Email: ronaldofaustino@recife.ifpe.edu.br
ORCID: https://orcid.org/0000-0001-8097-9420

Abstract: Sewage in Brazil represents 54.1% of sewage collected and 49.1% treated. Therefore, technologies must be innovative to remove contaminants so that they return to the environment within standards. Among the technologies: Water Quality Unit, traditional HDPE designed for the separation of solids and oils and a nanoceramic membrane reactor called Biogill, which has aerobic, anaerobic and anoxic phases associated with a BOD removal efficiency of 90% and nutrients of 80%. To contribute to the increase in these rates, an ETE was built in a residential building located in the city of Barra de São Miguel. The treated sewage was reused to produce Aroeira do Sertão and Ipê Roxo seedlings, as well as a morphophysiological and statistical analysis of the seedlings in relation to production with drinking water. Among the results: full compliance with CONAMA resolution nº 430/11; compliance with reuse standards ABNT NBR 13.969/1999, PROSAB, COEMA nº 2/2017 and SES/SMA/SSRH nº 1/2017, except turbidity and BOD, requiring improvements in tertiary treatment. Finally, the effluent showed better results for the development of seedlings than water, however, using ANOVA and Tukey's test ($p<0.05$), no significant classification was obtained.

Keywords: Environmental Technologies; Effluent Reuse; Ipe; Aroeira.

Resumo: O esgotamento no Brasil apresenta 54,1% dos esgotos coletados e 49,1% tratados. Logo, tecnologias devem ser implementadas para remover os contaminantes para que retornem ao meio ambiente dentro dos padrões. Entre as tecnologias: Unidade de Qualidade de Água, tubulação em PEAD destinada a separar sólidos e óleos e reator de membranas nanocerâmicas denominado Biogill, que possui fases aeróbias, anaeróbias e anóxicas associadas a uma eficiência de remoção de DBO de 90% e nutrientes de 80%. Para contribuir com o aumento desses indíces, uma ETE foi construída em um residencial localizado na cidade de Barra de São Miguel. O esgoto tratado foi reutilizado para produção de mudas de aroeira do sertão e ipê roxo, bem como foi realizado uma análise morfofisiológica e estátistica das mudas em relação a produção com água potável. Entre os resultados: atendimento em sua totalidade a resolução CONAMA nº 430/11; atendimento às normas de reúso ABNT NBR 13.969/1999, PROSAB, COEMA nº 2/2017 e SES/SMA/SSRH nº 1/2017, exceto turbidez e DBO, sendo necessário melhorias no tratamento terciário. Por fim, o efluente apresentou melhores resultados para o desenvolvimento das mudas do que a água, contudo pela ANOVA e teste de tukey ($p<0,05$) não se obteve diferenciação significativa.

Palavras-chave: Tecnologias Ambientais; Reutilização do Esgoto; Ipê; Aroeira.

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1. Introduction

According to the National Environment Council, sanitary sewage is the generic name for residential and commercial liquid waste and seepage into the sewage system. Therefore, according to Law 14.026/21, one of the aspects of basic sanitation is the treatment of these effluents.

According to the National Sanitation Information System, service in urban areas with regard to sewage collection systems is 61.9%. As for wastewater treatment, it is 78.5%. However, when comparing the sewage generated and treated in all areas, the statistic is lower, reaching a rate of 49.1% (SNIS, 2019).

In a Sewage Treatment Plant (STP), the environmental, social and economic components are related. From a social point of view, it's a way of preventing water-borne diseases, from an environmental point of view it improves the quality of water bodies and from an economic point of view it increases industrial expansion.

Although Brazil is one of the world's richest countries in terms of fresh water, the contamination of watercourses, multiple uses and lack of management all contribute to pollution (PAULINO *et al*, 2012). According to the National Water Agency, of the 2,082.7 m^3/s withdrawn from water bodies, around 52% is used for irrigation, 23.8% for public supply and 9.1% for industry (ANA, 2019). In this sense, the reuse of treated domestic sewage becomes viable.

The application of treated sewage to forest species can help increase productivity and raw materials for the wood, pharmaceutical, food and cosmetics industries (SENAR, 2018).

According to Law 6.938/81, environmental degradation is understood as an adverse change in the quality of the environment. Deforestation is one of the main impacts on forest species. According to data from the Deter system of the National Institute for Space Research (INPE), between August 2019 and July 2020, there was a 34.5% increase in deforestation in the Amazon. According to Embrapa (2004), 98.8% of degraded areas are linked to production and extraction activities.

The aim is to evaluate the treatment of sanitary sewage from a residential home using a biological system with nanoceramic membranes for forestry reuse, comparing the morphophysiological aspects (plant height, stem diameter and number of leaves) of the forest species ipê roxo and aroeira do sertão through the application of treated effluent and drinking water.

2. Methodology

In order to analyze the entire project that was implemented, a number of variables were taken into consideration, including: the design of the WWTP, the physical-chemical and biological characterization parameters of the public water supply, treated effluent and soil, along with their monitoring plans, as well as the construction requirements of the seedling nursery.

2.1 Effluent Treatment Plant and Monitoring Plan

In order to define the WWTP, an analysis was made of the space available in the household and a physical-chemical characterization of the raw effluent was carried out. For sizing purposes, the following variables were used: flow rate of 32 m^3/day, adopting a return coefficient of 80%, per capita water consumption of 120 L/inhab.day and approximately 334 inhabitants.

As shown in figure 1, the project implemented had the following flow: pumping station, UQA, a BioGill technology unit, activated carbon filter, chlorination and contact tank. After treatment, the effluent was directed to a reuse tank and then distributed to the seedling production unit.

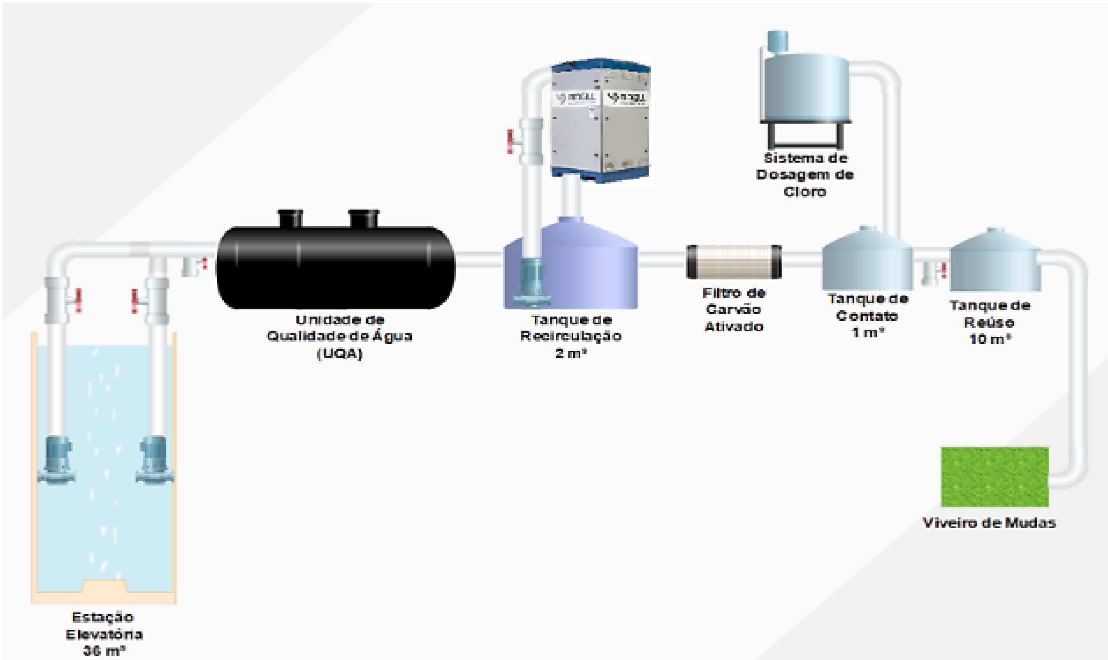

Figure 1 – Flowchart of the WWTP.
Source: Authors (2023).

Figure 2 – WWTP area.
Source: Authors (2023).

Figure 3 – ETE.
Source: Authors (2023).

After implementing the project, the biofilm was allowed to develop for 15 days and then the physical-chemical and biological characterization of the soil and drinking water was carried out in a private laboratory, with the exception of pH and temperature, which were carried out in the field. It should be noted that only one water analysis was carried out due to the low variability in the parameters. As for the effluent, the analyses were always carried out on the last day of the month and in a private laboratory, totaling four analyses. The raw effluent was collected after the pumping station and the treated effluent after the contact tank

The soil was collected using the Embrapa (2012) methodology, which consisted of collecting around 20 simple 500-gram samples of soil at different points at a depth of up to 20 cm, from which 500 grams of the soil mixture was collected and stored in a plastic bag for forwarding and analysis. Two soil analyses were carried out: before the treated effluent was irrigated and after the end of the experiment, in order to check the final condition of the soil after fertigation. Figure 4 shows the soil collection.

Figure 4 – Soil collection.
Source: Authors (2023).

Tables 1 and 2 list the analyses that were carried out during the period, as well as their quantities.

Table 1 – Sewage Monitoring Plan.

Parameter	Analysis Number (Water)	Analysis Number (Effluent)
BOD	1	4
pH	1	4
Temperature	1	4
Calcium	1	4
Magnesium	1	4
Sodium	1	4
Sodium Adsorption Ratio (SAR)	1	4
SST	1	4
Turbidity	1	4

Source: Authors (2023).

Table 2 – Soil Monitoring Plan.

Parameter	Number of Analyses
Base Saturation Index	2
pH	2
Organic material	2
Phosphorus	2
Potassium	2
Iron	2
Calcium	2
Sodium	2
Magnesium	2
Aluminum	2
Zinc	2
Copper	2
Manganese	2
CTC	2
Total Sand	2
Silt	2
Clay	2

Source: Authors (2023).

2.2 Characterization of the Nursery

The definition of the forest species and the construction of the nursery were assisted by the Institute for the Preservation of the Atlantic Forest (IPMA). IPMA is a scientific and preservationist institution focused on implementing forest conservation and regeneration programs (IPMA, 2019). The seeds chosen were ipê roxo and aroeira do sertão, provided by the institute, because, according to Oliveira (2016), both species do not require fertilization, so only drinking water (without fertilization) and treated sewage were used to demonstrate fertigation and finally the results were compared based on the reuse standards: ABNT-NBR 13.969/1997, PROSAB (2007), COEMA nº 2/2017 and SES/SMA/SSRH nº 1/2017.

As for the seedling nursery, one was created for 4 months, occupying 10 m^2 with 75% shade. Figure 5 shows the nursery.

Figure 5 – Seedling nursery.
Source: Authors (2023).

For the experiment, 40 seeds were used (20 seeds of each forest species). The seeds were placed in standard 1 kg plastic bags (figure 6) and buried at a depth of 0.5 to 1 cm. This production method was used due to its lower purchase cost, lower planting stress and efficiency.

Figure 6 – Soil in the bags.
Source: Authors (2023).

The seedlings were irrigated with 100% potable water and the others with 100% treated effluent. The system used was micro-spray. Each system used a pump and polyethylene tanks with a capacity of 10 m^3 (treated effluent) and 1 m^3 (drinking water). Irrigation took place twice a day: early in the morning and late in the afternoon. The amount of water needed for irrigation and the irrigation time were determined using the methodology of Marouelli and Braga (2016), which takes into account the following variables: irrigation shift, crop evapotranspiration, irrigation system efficiency and water application intensity. The calculations were carried out daily and passed on to the WWTP operator, who carried out the irrigation. It should be noted that the irrigation shift took into account data provided by the IPMA: an irrigation system with a water application intensity of 17.5 mm/h and an efficiency of 70%. Embrapa (2022) considers that a micro-sprinkler system has an efficiency of 70% to 90% and an application intensity of 14 to 18 mm/h.

2.3 Statistical analysis

After the seeds had germinated, the experimental units were distributed in a Completely Randomized Design (CID). DIC is used for experiments under homogeneous conditions and is the simplest of the designs, where the treatments are assigned by drawing lots. Figure 7 shows the experimental design.

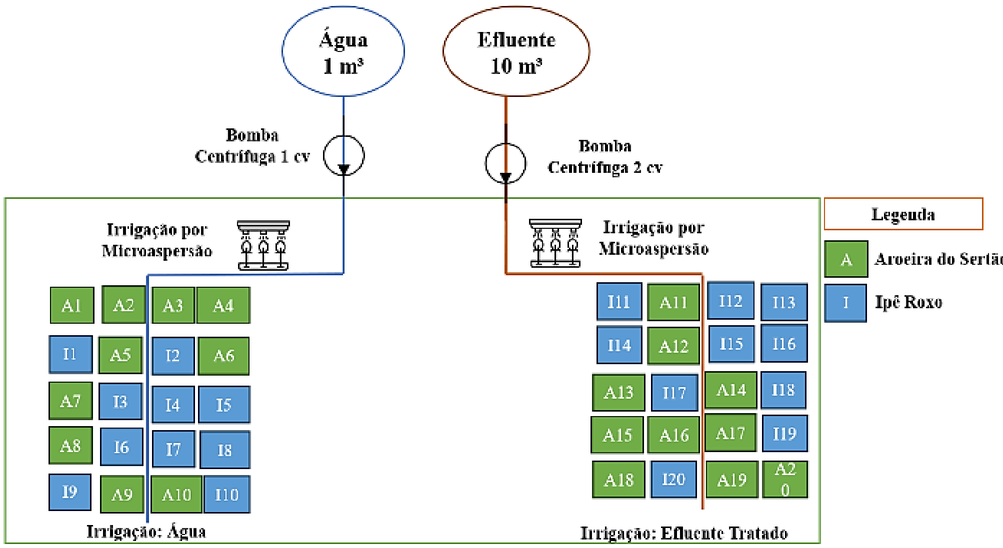

Figure 7 – DIC.
Source: Authors (2023).

Data was monitored every 14 days over four months and extracted using a millimeter ruler (plant height), digital caliper (stem diameter) and visually (number of leaves). The treatments were labeled: treated sewage and water supply. Sisvar 5.6 and Past 4.06 software were used for data analysis.

3. Results and discussion

Based on the project conditions implemented, it was possible to show the preliminary characterization of the effluent, the quality of the drinking water supply and the raw and treated effluent, the soil and irrigation conditions, as well as the morphophysiological growth of the ipê roxo and aroeira do sertão seedlings, and these results were statistically evaluated.

3.1 Project characterization

To carry out the WWTP project, the available area and the raw effluent were evaluated. Table 3 shows the results.

Table 3 – Characterization of the area and preliminary analysis of the effluent.

Parameter	Results
Available area (m^2)	210
BOD (mg/L)	306,3
COD (mg/L)	671,1
pH	6,9
Temperature (ºC)	25
Ssd (mL/L)	0,2

Source: Authors (2023).

According to Metcalf (2003), the residential effluent is classified as high concentration, since it has BOD above 300 mg/L and COD above 650 mg/L.

3.2 Water and Effluent Assessment

Throughout the experiment, one water analysis was carried out, while four effluent analyses were carried out, considering the parameters shown in table 1. Table 9 shows the average results.

Table 4 – Average results for water and effluents.

Parameter	Water	Raw Effluent	Treated Effluent
BOD (mg/L)	<3	356,9	32,5
pH	7,1	6,7	7,6
Temperature (ºC)	24	28,7	28,0
Calcium (mg/L)	1,23	-	16,3
Magnesium (mg/L)	6,6	-	3,5
Sodium (mg/L)	11	-	168,9
RAS	5,5	-	56,1
TSS (mg/L)	5	-	9,1
Turbidity (NTU)	7,9	-	5,7
Total Coliforms (MPN/100 mL)	0	-	56,4
Residual Chlorine (mg/L)	0,2	-	0,7
Boron (mg/L)	0,1	-	0,1
Ssd (mL/L)	-	0,87	0,2

Source: Authors (2023).

With regard to water, the city of Barra de São Miguel has 92.71% of its population with a water supply network (SNIS, 2019). According to the studies by Bezerra and Andrade (2016), Siqueira (2016) and Aparecida *et al* (2020), the results of the water, summarized in Table 4, are as expected. In relation to the variability of the quality, Sangel and Cavalcanti (2013) mention that the water shows low variability, except for the color and iron parameters which vary according to the hydroclimatic factors, i.e., it is evident that the work, despite having carried out only one water collection in the summer period, there was a low variability of the stipulated parameters, since the hydroclimatic factors remained similar.

With regard to the effluent, various treatment technologies can be used to generate sewage of excellent quality for reuse. Experiments involving stabilization ponds in series such as Arnaldo *et al* (2007) and Queiroz *et al* (2015), UASB reactors with stabilization ponds such as Silva (2011) and Lambais *et al* (2019), produce a treated effluent of good quality for reuse. Regarding experiments involving the BioGill reactor, no studies focused on reuse were found, however the experiments by Taylor (2013) and Duarte (2021) show satisfactory treated effluent results.

Furthermore, considering the results shown in Table 4 and comparing them with the reuse standards, it is possible to see that they comply with the standards.

As for NBR 13.969/1997, it complies with all the standards except turbidity, which should be less than 5 NTU. The NBR has two classes: class 2 for reuse in washing floors, sidewalks and garden irrigation, which is not included in this class, and class 4 for orchards, fodder, cattle pastures and irrigated crops, which is fully complied with. In relation to the PROSAB standard (2007), it is fully complied with for irrigation such as parks and ornamental uses. As for COEMA 2/2017, it is fully complied with, except for the RAS parameter, for agricultural purposes. Finally, as for SES/SMA/SSRH No. 1/2017, this standard segregates into two uses: moderate - partially met, except for turbidity which should be less than or equal to 2 NTU, thermotolerant coliforms which should be less than 200 NMP/100 mL, RAS which should be between 3 and 9 and BOD which should be less than or equal to 30 mg/L. This modality includes landscape irrigation, street washing, construction, vehicle washing and firefighting. The severe modality, on the other hand, was partially met, except for turbidity, which should be less than or equal to 2 NTU, BOD, which should be less than or equal to 10 mg/L, absent thermotolerant coliforms and RAS of less than 3. This modality focuses on landscape irrigation, street washing and construction.

This shows that improvements can be made to the WWTP, especially in tertiary treatment, by adopting sand filters to reduce organic material and solids and improvements to the chlorine dosing system to completely eliminate thermotolerant coliforms, as well as adopting a softener to eliminate salts in the effluent.

3.3 Soil

With regard to the physico-chemical analysis of soil parameters, two analyses were carried out: one before fertigation and one after fertigation. Tables 5 and 6 show the results.

Table 5 – Physical Analysis of the Soil.

Parameter	Results
Coarse sand (g/kg)	339
Fine Sand (g/kg)	216
Total Sand (g/kg)	555
Silt (g/kg)	225
Clay (g/kg)	220

Source: Authors (2023).

Table 6 – Chemical Analysis of the Soil.

Parameter	Pre-fertilization	Post-fertilization
Base Saturation Index (%V)	84,9	82,2
pH	7	6,7
Total Organic Matter (%)	2,6	11,9
P (mg/L)	11	202
K (mg/L)	75	197
Fe (mg/L)	169,1	52,3
Ca (meq/100mL)	2,6	4,8
Na (mg/L)	30	82
Mg (meq/100mL)	2,7	2,2
Al (meq/100mL)	0	0
Zn (mg/L)	0,1	19,5

Cu (mg/L)	1	1
Mn (mg/L)	0,3	40,8
CTC (c.molc/dm³)	5,6	7,8

Source: Authors (2023).

Considering table 4 and using the textual triangle - figure 8 - as a basis, it is clear that the soil is classified as loamy/sandy. The loamy soil found is considered to be a soil with practically equal properties of sand, silt and clay (Brady *et al*, 2013). Centeno *et al* (2017) mentions that the soil has good drainage and water retention capacity, as well as a medium level of erodibility. In contrast, the CPRM (2005) mentions that the soils in this region are considered deep and have low natural fertility, which was not evidenced.

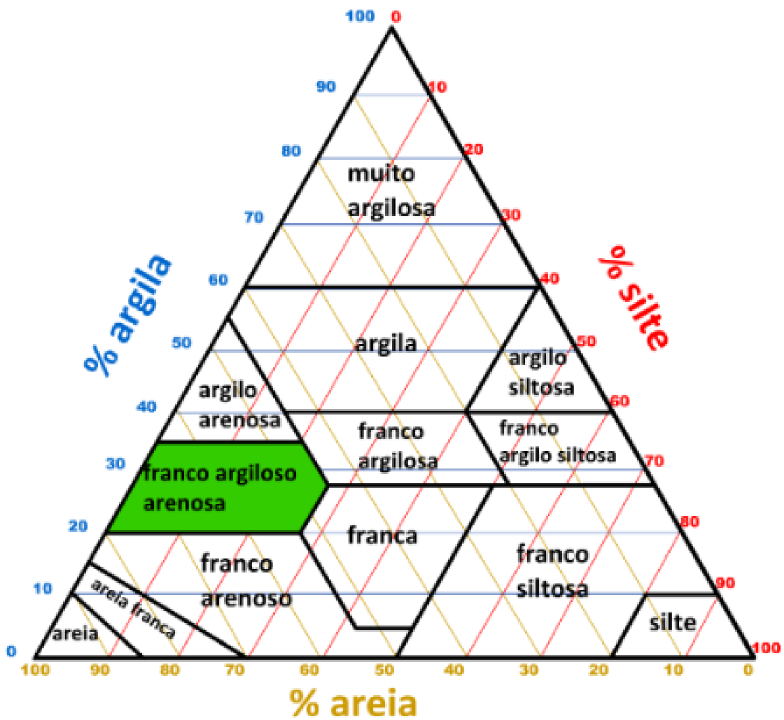

Figure 8 – Soil classification.
Source: Authors (2023).

3.4 Irrigation

Considering the methodology of Marouelli and Braga (2016), Table 7 shows the average results for temperature, humidity, irrigation rate and time. Almeida (2009) mentions that micro-sprinkler systems are the most affected by sediment, which reduces the useful life of irrigation system components, as well as the presence of filamentous bacteria that can clog sprinklers.

According to Table 4, Nakayama and Bucks (1986) mention that the presence of suspended solids of less than 50 mg/L and bacterial populations of less than 10,000 MPN/100 mL are not restrictions for use. Thus, throughout the experiment, the sprinklers did not present any clogging problems.

Table 7 – Average irrigation results.

Parameter	Results
Daytime Temperature (ºC)	27,33
Humidity of the Day (%)	69,04
Blade to be applied (mm)	4,44
Irrigation time (min)	15,18

Source: Authors (2023).

Arnaldo *et al* (2007), using treated domestic sewage to produce seedlings, used only irrigation based on the flow rate of the micro-sprinklers, obtaining good development. Oliveira (2015) used a conventional sprinkler system with a uniform irrigation rate and time based on the coefficient of infiltration of the effluent into the soil, calculating the rate based on the evapotranspiration rates of the crop, crop coefficient and reference evapotranspiration, obtaining satisfactory results in terms of plant development. Amaral *et al* (2019) used the pot capacity technique. Therefore, different irrigation methodologies can be used to obtain satisfactory results.

3.5 Forest species

Tables 8 and 9 show the results for the forest species - aroeira do sertão (A) and ipê roxo (I) in terms of the following parameters: plant height (H), stem diameter (D) and number of leaves (NF). All the data was collected in the year 2022, totaling 140 data points for each parameter.

According to the tables below, the results for aroeira do sertão began to be collected in the first week of the experiment, while those for ipê started in the second. Oliveira (2016) states that ipê roxo germinates between 2 and 4 weeks, while aroeira do sertão germinates between 1 and 3 weeks. It is important to note that treatments A2, I2, I4 and I13 did not develop.

With regard to treatment A2, the Northeastern Center for Plant Information points out that one of the main causes of the failure to grow is due to the poor collection of the seed, which may not have been collected ripe. In relation to treatments I2, I4 and I13, Alves and Schlindwein (2018) mention that the main factor in the failure of the ipê roxo to grow is acidic soil, which affects the availability of nutrients, but this is not shown in table 5. It is important to carry out further studies to identify the specific causes of the failure to grow.

It should be noted that visually the seedlings did not show any morphophysiological changes, i.e. specific diseases such as chlorosis.

Figure 9 – Final Result of Seedling Development: from left to right (irrigated with water and irrigated with sewage). Source: Authors (2023).

Table 8 – Aroeira do Sertão results.

Type	17/Sep			01/Oct			15/Oct			29/Oct			12/Nov			26/Nov			10/Dec		
	H	**D**	**NF**	**H**	**D**	**NF**	**H**	**D**	**NF**	**H**	**D**	**NF**	**H**	**D**	**NF**	**H**	**D**	**NF**	**H**	**D**	**NF**
A1	0	0	0	3,5	0,3	17	5,75	0,75	57	8	1,2	100	9	1,5	105	9,2	1,5	115	9,6	2,37	120
A2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A3	14	0,67	3	21	1,73	12	23,5	1,73	13	26	1,73	14	26	2,4	41	39	3,06	73	58	4,4	87
A4	0	0	0	1,5	0,67	5	2,75	0,74	9	4	0,81	14	9	0,97	30	24	2,89	139	44	2,92	166
A5	0	0	0	0	0	0	4	1,41	5	8	1,53	11	10,5	1,7	16	11	1,94	28	12,3	1,97	33
A6	0	0	0	0	0	0	4	1,27	5	8	1,51	11	10,5	1,7	16	12,5	1,88	23	13	2,13	40
A7	0	0	0	0	0	0	2	0,72	10	7	1,34	27	9,5	1,51	35	10,5	1,59	41	14	2,15	48
A8	0	0	0	0	0	0	0	0	0	0	0	2	4	0,82	8	5,1	0,97	17	8,8	1,74	29
A9	0	0	0	3	1,65	24	4,25	1,69	25	5,5	1,73	26	12	2,14	35	30	3,18	77	39	4,74	109
A10	0	0	0	0	0	0	0	0	0	0	0	0	1,2	0,98	4	2,75	1,21	13	3,9	1,37	25
A11	0	0	0	0	0	0	0	0	0	0	0	0	2,5	0,97	4	3,8	1,17	6	7,4	2,05	17
A12	0	0	0	0	0	0	0	0	0	0	0	0	1,02	0,98	76	1,72	1,58	80	9,5	1,65	126
A13	0	0	0	1	0,41	2	9	1,12	3	17	1,96	5	17,2	1,98	7	18	2,12	16	19,2	2,87	27
A14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	3,32	11	40	4,8	19
A15	0	0	0	0	0	0	0	0	0	1,8	0,17	6	2,5	0,38	7	5	0,63	15	7	1,48	16
A16	20	1,04	4	20	1,92	15	24	1,93	17	28,5	1,94	19	35	2,7	24	43	3,89	74	44	5	98
A17	0	0	0	0	0	0	7,2	1,37	14	8,5	2,35	23	18	2,55	36	49	3,61	45	53,5	3,77	87
A18	0	0	0	3	0,68	19	6	1,03	42	9	1,39	55	11	1,7	66	17	1,82	73	17,6	1,92	93
A19	0	0	0	0	0	0	1,5	1,03	21	1,8	1,39	27	1,92	1,52	39	5	1,96	16	22	1,97	58
A20	0	0	0	2,5	0,28	2	4,75	0,81	9	7	1,34	17	7,7	1,36	19	7,9	1,44	20	10,4	1,77	27

Source: Authors (2023).

Table 9 – Purple Ipe results.

Type	**17/Sep**			**01/Oct**			**15/Oct**			**29/Oct**			**12/Nov**			**26/Nov**			**10/Dec**		
	H	**D**	**NF**	**H**	**D**	**NF**	**H**	**D**	**NF**	**H**	**D**	**NF**	**H**	**D**	**NF**	**H**	**D**	**NF**	**H**	**D**	**NF**
A1	0	0	0	3,5	0,3	17	5,75	0,75	57	8	1,2	100	9	1,5	105	9,2	1,5	115	9,6	2,37	120
A2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
A3	14	0,67	3	21	1,73	12	23,5	1,73	13	26	1,73	14	26	2,4	41	39	3,06	73	58	4,4	87
A4	0	0	0	1,5	0,67	5	2,75	0,74	9	4	0,81	14	9	0,97	30	24	2,89	139	44	2,92	166
A5	0	0	0	0	0	0	4	1,41	5	8	1,53	11	10,5	1,7	16	11	1,94	28	12,3	1,97	33
A6	0	0	0	0	0	0	4	1,27	5	8	1,51	11	10,5	1,7	16	12,5	1,88	23	13	2,13	40
A7	0	0	0	0	0	0	2	0,72	10	7	1,34	27	9,5	1,51	35	10,5	1,59	41	14	2,15	48
A8	0	0	0	0	0	0	0	0	0	0	0	2	4	0,82	8	5,1	0,97	17	8,8	1,74	29
A9	0	0	0	3	1,65	24	4,25	1,69	25	5,5	1,73	26	12	2,14	35	30	3,18	77	39	4,74	109
A10	0	0	0	0	0	0	0	0	0	0	0	0	1,2	0,98	4	2,75	1,21	13	3,9	1,37	25
A11	0	0	0	0	0	0	0	0	0	0	0	0	2,5	0,97	4	3,8	1,17	6	7,4	2,05	17
A12	0	0	0	0	0	0	0	0	0	0	0	0	1,02	0,98	76	1,72	1,58	80	9,5	1,65	126
A13	0	0	0	1	0,41	2	9	1,12	3	17	1,96	5	17,2	1,98	7	18	2,12	16	19,2	2,87	27
A14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	3,32	11	40	4,8	19
A15	0	0	0	0	0	0	0	0	0	1,8	0,17	6	2,5	0,38	7	5	0,63	15	7	1,48	16
A16	20	1,04	4	20	1,92	15	24	1,93	17	28,5	1,94	19	35	2,7	24	43	3,89	74	44	5	98
A17	0	0	0	0	0	0	7,2	1,37	14	8,5	2,35	23	18	2,55	36	49	3,61	45	53,5	3,77	87
A18	0	0	0	3	0,68	19	6	1,03	42	9	1,39	55	11	1,7	66	17	1,82	73	17,6	1,92	93
A19	0	0	0	0	0	0	1,5	1,03	21	1,8	1,39	27	1,92	1,52	39	5	1,96	16	22	1,97	58
A20	0	0	0	2,5	0,28	2	4,75	0,81	9	7	1,34	17	7,7	1,36	19	7,9	1,44	20	10,4	1,77	27

Source: Authors (2023).

3.6. Statistical analysis

Analysis of variance (ANOVA) compares the variances between treatment averages, helping to identify statistical similarities or differences (TIBCO, 2019). In order to apply ANOVA, three basic assumptions are essential: the observations must be independent, the distribution must be normal and the variances in each group must be approximately equal. However, the tool does not help to identify which treatment differs from each other, so it is necessary to perform the Tukey test (OLIVEIRA, 2019). Oliveira (2019) mentions that the Tukey test compares all treatment pairs.

In this experiment, it was necessary to check the ANOVA assumptions in order to proceed with the Tukey test, and it was necessary to carry out the Shapiro-Wilk test. The test showed that there was no normality ($p<0.05$) in the data due to heterogeneity, making it necessary to perform a data transformation to comply with the ANOVA assumptions. The data transformation was carried out by applying the square root formula, the most commonly used method for counting processes, to the plant height and stem diameter data for aroeira do sertão and plant height for ipê roxo. After data transformation, the data was found to be normal. The tables below show the statistical analysis carried out on the final results of seedling development after data transformation.

Table 10 – Statistical analysis of Aroeira do Sertão.

Analysis of Variance			
Parameter	**Overall Average**	**Pr>Fc**	**Coefficient of Variation (%)**
Plant height	4,2295	0,5286	47,80
Stem diameter	1,5230	0,4436	32,98
Number of Leaves	61,2500	0,6774	76,83
Tukey test			
Parameter	**Water**	**Sewage**	
Plant height	3,9390 b	4,5200 b	
Stem diameter	1,4350 b	1,6110 b	
Number of Leaves	65,7000 b	56,8000 b	

Averages followed by different letters differed according to the Tukey test ($p<0.05$).

Source: Authors (2023).

Table 11 – Statistical analysis of Ipê Roxo.

Analysis of Variance			
Parameter	**Overall Average**	**Pr>Fc**	**Coefficient of Variation (%)**
Plant height	3,3315	0,6086	59,63
Stem diameter	2,0280	0,9056	64,17
Number of Leaves	49,9000	0,3556	73,72
Tukey test			
Parameter	**Water**	**Sewage**	
Plant height	3,1000 b	3,5630 b	
Stem diameter	1,9930 b	2,0630 b	
Number of Leaves	42,1000 b	57,7000 b	

Averages followed by different letters differed according to the Tukey test ($p<0.05$).

Source: Authors (2023)

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Table 10 and 11 show that the "pr> fc" ratio was greater than 0.05 for all parameters and both forest species, indicating that the treatments are not significant, i.e. they are statistically equal. With regard to the coefficient of variation, Gomes (2009), in agricultural experiments, classified it as high, i.e. all the parameters had a high coefficient, which is justified by the great heterogeneity of the data

Using the Tukey test, the results did not differ, so statistically they are the same. Although the analysis between the treatments is the same, it can be seen that the treated effluent showed the highest averages for all the parameters of seedling development, except for the number of leaves of the aroeira do sertão.

Arnaldo *et al* (2007), using treated domestic sewage to produce seedlings of caatinga forest species, including ipê roxo, found that the treatments interacted significantly. The ipê roxo seedlings irrigated with effluent had lower initial growth than those irrigated with water and after 30 days of the experiment they showed superior development for the variables of plant height and stem diameter. Figure 10 shows graphically that after 28 days of cultivation, the seedlings irrigated with treated effluent performed better than those irrigated with water in terms of plant height. Figure 11, on the other hand, shows that it was only possible to verify a larger stem diameter for the treated effluent seedlings after 98 days of the experiment.

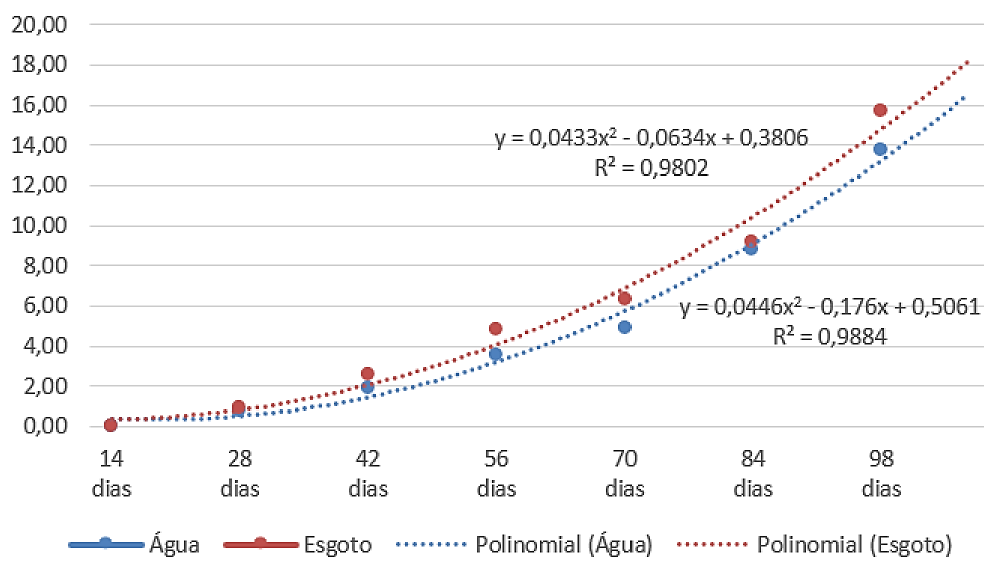

Figure 10 – Graphical comparison of the Purple Ipe at each stage for the plant height parameter.
Source: Authors (2023).

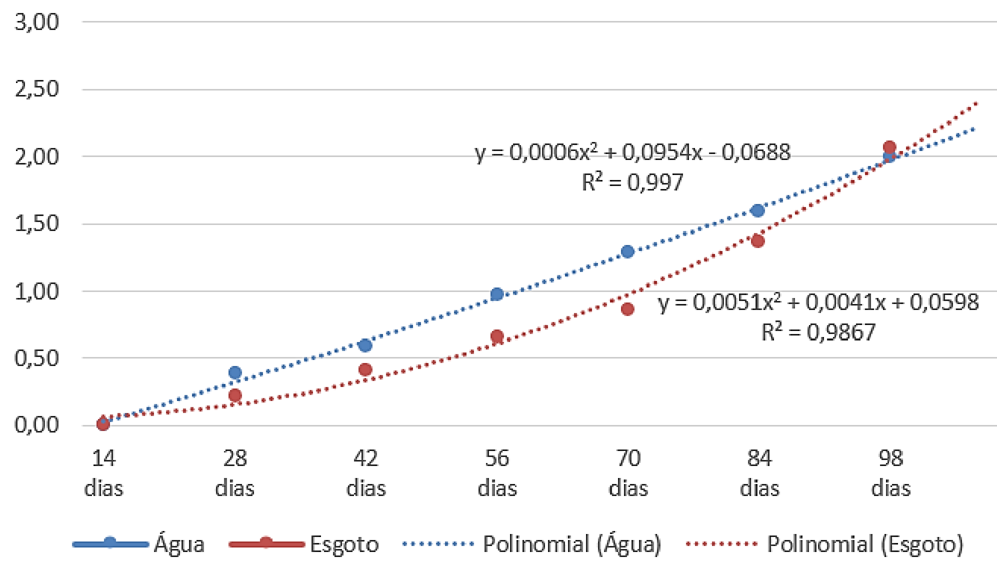

Figure 11 – Graphical comparison of the Purple Ipe at each stage for the stem diameter parameter.
Source: Authors (2023).

Amaral *et al* (2019), producing ipê roxo seedlings irrigated with treated effluent, found that the average plant height for seedlings irrigated with sewage was 1.94 cm higher when compared to those irrigated with water. He also found that there was no significant difference in the number of average leaves, which is also evident in this study, as shown in the figure below.

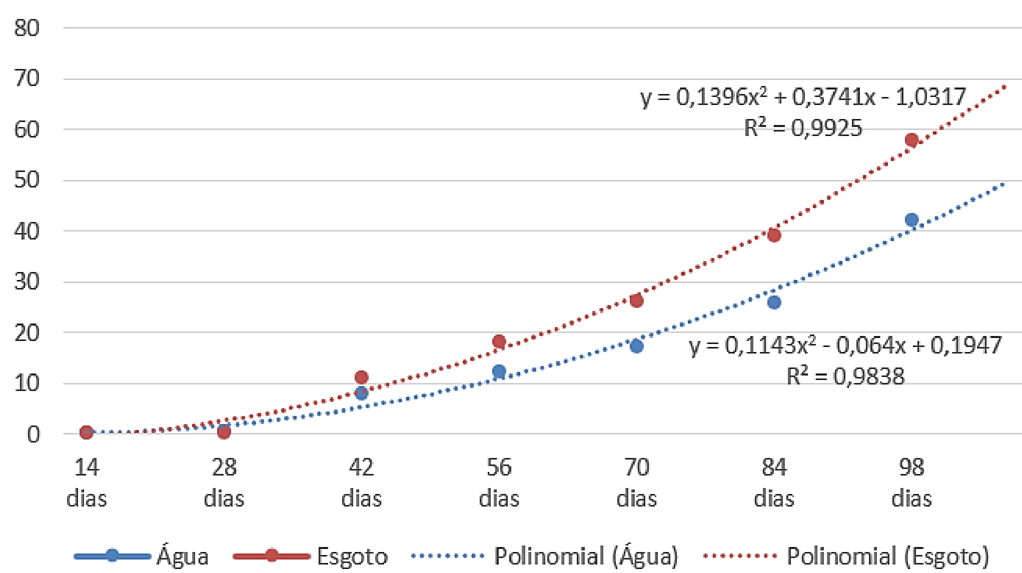

Figure 12 – Graphical comparison of the Purple Ipe at each stage for the number of leaves parameter.
Source: Authors (2023).

Arnaldo (2006), producing forest seedlings of ipê roxo and aroeira do sertão in a DIC with treated sewage and water over a period of 105 days, found that the seedlings had a greater average height when irrigated with effluent than with water. For aroeira 14.72 cm and 24.48 respectively and ipê around 13 cm and 24.3 cm, respectively. It was also found that the treatments for these seedlings statistically varied significantly in terms of irrigation. With regard to stem diameter, for both species, the treated sewage showed the best response. For mastic, 3.37 mm and 3.84 mm, and ipê, around 6.68 mm and 10.34 mm, in that order. With regard to this parameter, the author also found that the mastic tree treatments were not affected by the quality of the irrigated water and had similar diameters, with only those of ipê roxo being affected. The figures below show the results graphically for aroeira do sertão.

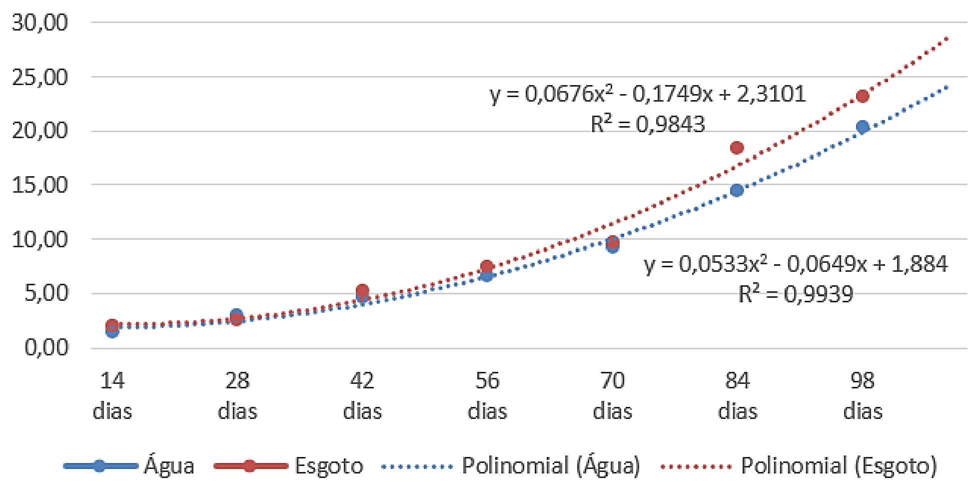

Figure 13 – Graphical comparison of Aroeira do Sertão at each stage for the plant height parameter. Source: Authors (2023).

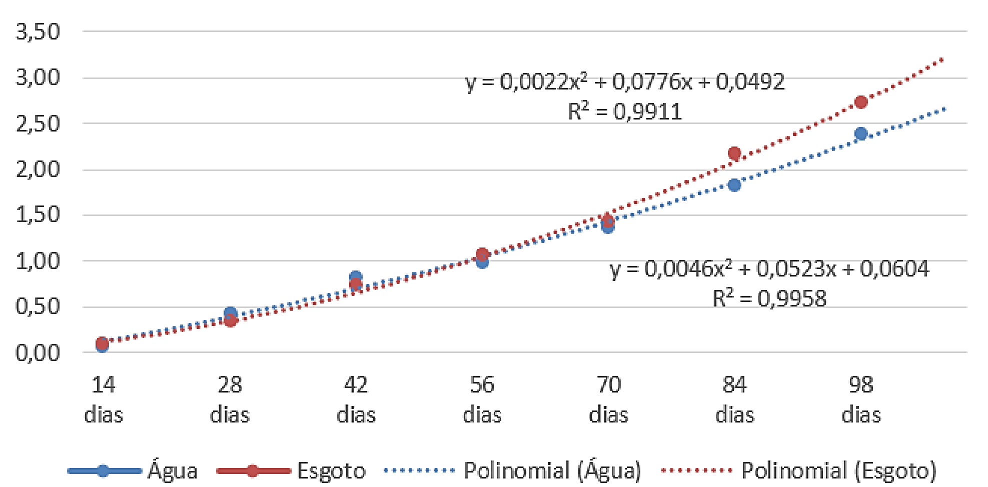

Figure 14 – Graphical comparison of Aroeira do Sertão at each stage for the stem diameter parameter. Source: Authors (2023).

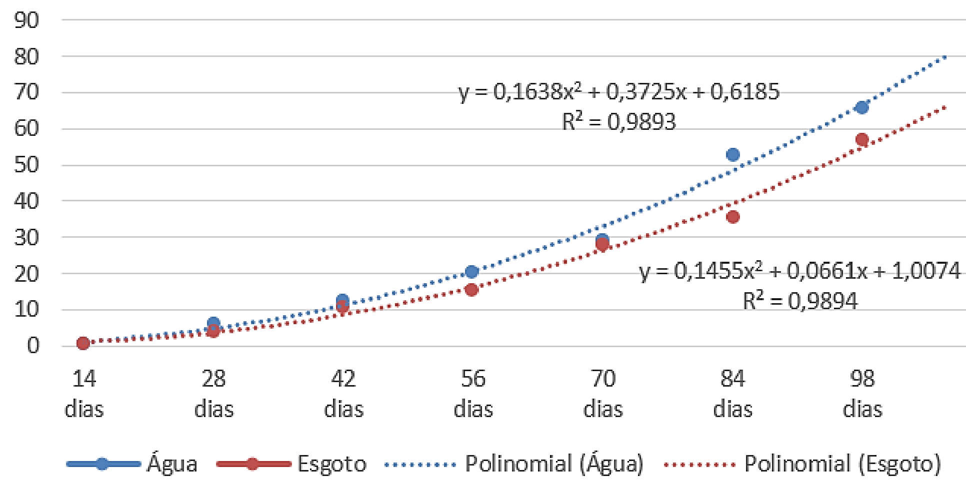

Figure 15 – Graphical comparison of Aroeira do Sertão at each stage for the number of leaves parameter. Source: Authors (2023).

Brito *et al* (2018) using wastewater in the production of aroeira do sertão seedlings in a DIC lasting 150 days, found that the development of the seedlings in terms of height, diameter and number of leaves was significantly greater than those irrigated with water. Both treatments showed a significant difference using the 5% Tukey test.

Although the statistical data was not significantly different, the average seedling growth for both species was higher in the treated effluent due to the higher concentration of macronutrients and organic material. As for the number of leaves, the only parameter for which the water obtained a higher result than the treated effluent, in the case of aroeira do sertão, this can be explained by the time of the experiment, Brito *et al* (2018) states that until the initial 90 days, the species has not yet entered the climax stage. In addition, Pacheco *et al* (2011) states that due to the genetic variability explained by the physiological heterogeneity of the seeds, this may be a factor that affects development.

4. Final Considerations

Based on the results presented, it was possible to identify the following conclusions:

a) The treated effluent did not meet the reuse standards of ABNT NBR 13.969/1997 and SES/SMA/SSRH Nº 1/2017 in its entirety, especially with regard to the parameters of turbidity and BOD, making it necessary to adopt improvements in tertiary treatment;

b) The treated effluent showed better results for the morphophysiological development of the seedlings, both for the aroeira do sertão and the ipê roxo, due to the high concentration of nutrients and organic material compared to water, except for the number of leaves for the aroeira do sertão, but statistically by the 5% Tukey test there were no significant differences in terms of irrigation quality;

c) The practice of effluent reuse should be more widespread due to its great economic and environmental viability;

d) Further studies should be carried out to identify the causes of the non-growth of seedlings A2, I2, I4 and I13, given that the experiment in question complied with all the control variables.

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